SLOVENSKI STANDARD
SIST ISO/TR 13387-3:2001

01-februar-2001

Požarno inženirstvo - 3. del: Ocenjevanje in preverjanje matematičnih požarnih modelov

Fire safety engineering -- Part 3: Assessment and verification of mathematical fire models

Ingénierie de la sécurité contre l'incendie -- Partie 3: Évaluation et vérification des modèles mathématiques

Ta slovenski standard je istoveten z: **ISO/TR 13387-3:1999**

ICS:

13.220.01	Varstvo pred požarom na splošno	Protection against fire in general

SIST ISO/TR 13387-3:2001 **en**

TECHNICAL REPORT

ISO/TR 13387-3

First edition
1999-10-15

Fire safety engineering —

Part 3:
Assessment and verification of mathematical fire models

Ingénierie de la sécurité contre l'incendie —
Partie 3: Évaluation et vérification des modèles mathématiques

Reference number
ISO/TR 13387-3:1999(E)

Contents

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Printed in Switzerland

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The main task of ISO technical committees is to prepare International Standards, but in exceptional circumstances a technical committee may propose the publication of a Technical Report of one of the following types:

— type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;

— type 2, when the subject is still under technical development or where for any other reason there is the future but not immediate possibility of an agreement on an International Standard;

— type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard ("state of the art", for example).

Technical Reports of types 1 and 2 are subject to review within three years of publication, to decide whether they can be transformed into International Standards. Technical Reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

ISO/TR 13387-3, which is a Technical Report of type 2, was prepared by Technical Committee ISO/TC 92, *Fire safety*, Subcommittee SC 4, *Fire safety engineering*.

It is one of eight parts which outlines important aspects which need to be considered in making a fundamental approach to the provision of fire safety in buildings. The approach ignores any constraints which might apply as a consequence of regulations or codes; following the approach will not, therefore, necessarily mean compliance with national regulations.

ISO/TR 13387 consists of the following parts, under the general title *Fire safety engineering:*

— *Part 1: Application of fire performance concepts to design objectives*

— *Part 2: Design fire scenarios and design fires*

— *Part 3: Assessment and verification of mathematical fire models*

— *Part 4: Initiation and development of fire and generation of fire effluents*

— *Part 5: Movement of fire effluents*

— *Part 6: Structural response and fire spread beyond the enclosure of origin*

— *Part 7: Detection, activation and suppression*

— *Part 8: Life safety — Occupant behaviour, location and condition*

Annex A of this part of ISO/TR 13387 is for information only.

Introduction

ISO/TR 13387 describes a systematic engineering approach to addressing fire safety in buildings. Other parts of the Technical Report address fire spread, smoke movement, fire detection and suppression, and life safety. The objective of fire safety engineering is to assist in the creation of buildings which have an acceptable predicted level of fire safety. Part of this work involves the use of mathematical models to predict the course of events of potential fires in those buildings. Part 3, which addresses the assessment and verification of mathematical models for fire prediction, applies to mathematical fire models in general and not just to those that are part of the ISO fire safety engineering framework. Although the current focus of the document is on fire in buildings, it may also be used to assess fire models that concern other fires, such as outdoor fires and transportation fires.

Totally deterministic and totally probabilistic approaches to fire safety engineering are used today. Mathematical fire models are usually deterministic but sometimes contain probabilistic elements.

When combined, mathematical descriptions of physical phenomena and people movement can be programmed to create complex computer codes that estimate the expected course of a fire based on given input parameters. Mathematical fire models have progressed to the point of providing good predictions for some parameters of fire behaviour. However, input data is not always available, and many factors that affect the course of a fire, such as the position of doors or the location of people, are probabilistic in nature and cannot be determined from physics. These data and probabilistic factors require engineering judgement. For more detailed discussion of deterministic and probabilistic approaches to fire safety engineering the reader should refer to part 1 of ISO/TR 13387. The assessment and verification of probabilistic elements or totally probabilistic approaches are not addressed in this part of ISO/TR 13387.

Potential users of deterministic fire models and those who are asked to accept the results need to be assured that the models will provide sufficiently accurate predictions of the course of a fire for the specific application planned. To provide this assurance, the model(s) being considered should be verified for physical representation and mathematical accuracy. Verification involves checking that the theoretical basis and assumptions used in the model are appropriate, that the model contains no serious mathematical errors, and that it has been shown, by comparison with experimental data, to provide predictions of the course of events in similar fire situations with a known accuracy. It is understood that such comparisons cannot encompass every possible application of interest to the user. However, they should be representative of a range of similar applications. The fact that a model provides accurate predictions for one fire situation is not an absolute guarantee that it provides accurate predictions in a similar situation.

Concern for the accuracy of fire model predictions has been expressed by the international community of fire protection engineers and fire modelers themselves since the early models were published. The International Council for Building Research Studies and Documentation (CIB), Commission W14, Fire, recognized the need to expand international discussion on the use, application and limitations of fire models. The ISO task group that developed this ISO document used the ASTM standard guide[1] as a reference text, and has outlined a format for collecting and making available experimental data on fire development and smoke spread in buildings. In addition, the methodology embodied in ISO 9000 for quality assurance of software should be followed.

Included in this document are:

a) guidance on the documentation necessary to assess the adequacy of the scientific and technical basis of a model;

b) a general methodology to check a model for errors and test it against experimental data;

c) guidance on assessing the numerical accuracy and stability of the numerical algorithms of a model;

d) guidance on assessing the uncertainty of experimental measurements against which a model's predicted results may be checked;

e) guidance on the use of sensitivity analysis to ensure the most appropriate use of a model.

This document focuses on the predictive accuracy of mathematical fire models. However, other factors such as ease of use, relevance, completeness and status of development play an important role in the assessment of the use of the most appropriate model for a particular application.

Fire safety engineering —

Part 3:
Assessment and verification of mathematical fire models

1 Scope

This part of ISO/TR 13387 provides guidance on procedures for assessing and verifying the accuracy and applicability of deterministic mathematical fire models used as tools for fire safety engineering. It does not address specific fire models. It is not a step-by-step procedure, but does describe techniques for detecting errors and finding limitations in a calculation model. This part of ISO/TR 13387 does not address the assessment and verification of totally probabilistic approaches to fire safety calculations, or the probabilistic elements that may be combined with deterministic calculations.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO/TR 13387. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO/TR 13387 are encouraged to investigate the possibility of applying the most recent additions of the normative documents indicated below. For undated references, the latest addition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid international standards.

ISO/TR 13387-1, *Fire safety engineering — Part 1: Application of fire performance concepts to design objectives.*

ISO/TR 13387-2, *Fire safety engineering — Part 2: Design fire scenarios and design fires.*

ISO/TR 13387-4, *Fire safety engineering — Part 4: Initiation and development of fire and generation of fire effluents.*

ISO/TR 13387-5, *Fire safety engineering — Part 5: Movement of fire effluents.*

ISO/TR 13387-6, *Fire safety engineering — Part 6: Structural response and fire spread beyond the enclosure of origin.*

ISO/TR 13387-7, *Fire safety engineering — Part 7: Detection, activation and suppression.*

ISO/TR 13387-8, *Fire safety engineering — Part 8: Life safety — Occupant behaviour, location and condition.*

ISO 13943, *Fire safety — Vocabulary.*

3 Terms and definitions

For the purposes of this part of ISO/TR 13387, the terms and definitions given in ISO 13943, ISO/TR 13387-1 and the following apply.

3.1
engineering judgement
the process exercised by a professional who is qualified by way of education, experience and recognized skills to complement, supplement, accept or reject elements of a quantitative analysis

3.2
verification (as applied to mathematical fire models)
the process of checking a mathematical fire model for correct physical representation and mathematical accuracy for a specific application or range of applications

The process involves checking the theoretical basis, the appropriateness of the assumptions used in the model, that the model contains no unacceptable mathematical errors and that the model has been shown, by comparison with experimental data, to provide predictions of the course of events in similar fire situations with a known accuracy.

3.3
validation (as applied to fire calculation models)
the process of determining the correctness of the assumptions and governing equations implemented in a model when applied to the entire class of problems addressed by the model

4 Symbols and abbreviated terms

k coverage symbol

s_i standard deviation

U expanded uncertainty

u_c combined standard uncertainty

u_i standard uncertainty

u_j uncertainty component in category B (see 9.1)

v_i number of degrees of freedom

5 Potential users and their needs

This part of ISO/TR 13387 is intended for use by:

a) Model developers/marketers — to document the usefulness of a particular calculation method, perhaps for specific applications. Part of model development includes identification of precision and limits of applicability, and independent testing.

b) Model users — to assure themselves that they are using an appropriate model for an application and that it provides adequate accuracy. Mathematical models will be used mostly by professional engineers for fire safety design of buildings, fire hazard and risk analysis of new products, fire investigation and litigation. In litigation involving corporations from different countries, an ISO standard for assessment and verification of calculation methods is likely to form the basis for acceptance of those methods. This identification process should be undertaken by a team of stakeholders including the building owner, the architect and all design engineers (including a fire safety engineer), the building manager, the building inspector or other approval authority and a fire service representative.

c) Developers of model performance codes — to provide a means to detect invalid calculation procedures and avoid incorporating them into codes. Performance codes under development in a number of countries are likely to be models for fire codes in developing countries.

d) Approving officials — to ensure that the results of calculations using mathematical models stating conformance to this part of ISO/TR 13387, cited in a submission, show clearly that the model is used within its applicability limits and has an acceptable level of accuracy.

e) Educators — to demonstrate the application and acceptability of calculation methods being taught.

The importance of each clause of this part of ISO/TR 13387 will depend on the user. For example, model developers should be particularly interested in clause 6, Documentation, clause 8, Numerical accuracy, and clause 10, Sensitivity analysis. Whereas users, developers of model performance codes and approval officials will be more interested in clause 6, Documentation, clause 7, General methodology, clause 10, Sensitivity analysis, and clause 11, Reference fire tests.

6 Documentation

6.1 General

ASTM has published a standard guide for evaluating the predictive capability of fire models[1], and a number of papers have been published on the subject[2],[3],[4],[5],[6],[7],[8]. Annex A contains a review of the ASTM standard, a survey of fire models, and reviews of five of those publications.

The technical documentation should be sufficiently detailed that all calculation results can be reproduced within the stated accuracy by an independent engineer experienced in mathematics, numerical analysis and computer programming, but without using the described computer programme.

Sufficient documentation of calculation models, including computer software, is essential to assess the adequacy of the scientific and technical basis of the models, and the accuracy of computational procedures. Also, adequate documentation will help prevent the unintentional misuse of fire models. Reports on any assessment and verification of a specific model should become part of the documentation. The ASTM guide for documenting computer software for fire models[9] is the primary source for information contained in this clause.

Documentation of computer models should include technical documentation and a user's manual. The technical documentation, often in the form of a scientific or engineering journal publication, is needed to assess the scientific basis of the model. A user's manual should enable the user to understand the model application and methodology, reproduce the computer operating environment and the results of sample problems included in the manual, modify data inputs, and run the program for specified ranges of parameters and extreme cases. The manual should be concise enough to serve as a reference document for the preparation of input data and the interpretation of results. Installation, maintenance and programming documentation may be included in the user's manual or be provided separately. There should be sufficient information to install the programme on a computer. All forms of documentation should include the name and sufficient information to define the specific version of the model and identify the organization responsible for maintenance of the model and for providing further assistance.

The following subclauses describe the suggested contents of technical documentation and a user’s manual. The list is quite lengthy, but is not intended to exclude other forms of information that can assist the user in assessing the applicability and usability of the model.

6.2 Technical documents

Technical documentation should:

a) define the fire problem modelled, or the function performed by the model;

b) include any feasibility studies and justification statements;

c) describe the theoretical basis of the phenomena and the physical laws on which the model is based;

d) present the governing equations;

e) identify the major assumptions and limits of applicability;

f) describe the mathematical techniques, procedures and computational algorithms employed and provide references for them;

g) discuss the precision of the results obtained by important algorithms, and any dependence on particular computer capabilities;

h) list any auxiliary programmes or external data files required;

i) provide information on the source, contents and use of data libraries;

j) provide the results of any efforts to evaluate the predictive capabilities of the model;

k) provide references to reviews, analytical tests, comparison tests, experimental validation and code checking already performed;

l) indicate the extent to which the model meets this part of ISO/TR 13387.

6.3 User's manual

The user's manual should:

a) include a self-contained description of the programme;

b) describe the basic processing tasks performed, and the methods and procedures employed (a flow chart can be useful);

c) identify the computer(s) on which the programme can be executed, and any peripherals required;

d) provide instructions for installing the programme;

e) identify the programming languages and software operating systems and versions in use;

f) describe the source of input information and any special input techniques;

g) describe the handling of cases in which only minor differences are introduced between runs;

h) provide the default values or the general conventions governing them;

i) list any property values defined within the programme;

j) describe the contents and organization of any external data files;

k) list the operating-system control commands;

l) describe the programme output and any graphics display and plot routines;

m) provide information to enable the user to estimate the execution time on applicable computer systems for typical applications;

n) provide sample data files with associated outputs to allow the user to verify the correct operation of the programme;

o) list instructions for appropriate actions when error messages occur;

p) provide instructions on judging whether the programme has converged to a good solution where appropriate.

7 General methodology

7.1 General

In this part of ISO/TR 13387 the term "model" encompasses all the physical, mathematical and numerical assumptions and approximations that are employed to describe a particular fire process, movement of effluents, building or occupant response, and fire detection, activation or suppression system, including those boundary conditions that are necessary for its application to a particular scenario. This document is written on the assumption that the model is implemented as a programme on a digital computer. In order to check that such a computer model can satisfactorily represent physical reality, a process of verification is necessary to test the adequacy of a model's theoretical basis and implementation. Such a process requires that the computer code be fully documented to permit independent review of the theoretical assumptions and mathematical techniques used in the model. Whenever possible, the source code should be a part of the evaluation, but it is recognized that when commercial software is used the source code is often not available.

A verification methodology can be designed to reveal inappropriate methods or erroneous assumptions that can arise from any of the following sources:

a) the use of inappropriate algorithms or wrong physics to describe the fire processes and sub-processes that are being modelled,

b) the use of incorrect or unsubstantiated constants or default values;

c) the omission of (sub)-processes in describing the development of a fire (this is essentially that the model over-simplifies the phenomena which it is attempting to represent);

d) the use of inappropriate numerical algorithms to solve the equation set(s) that result from the application of algorithms to describe the (sub)-processes;

e) errors in the computer code.

The techniques for detecting errors in a model can be classified as:

a) review of the theoretical basis of the model;

b) code checking;

c) analytical tests;

d) inter-model comparison;

e) empirical validation.

7.2 Review of the theoretical basis of the model

The theoretical basis of the model should be reviewed by one or more experts fully conversant with the chemistry and physics of fire phenomena but not involved with the production of the model. This review should include an assessment of the completeness of the documentation, particularly with regard to the assumptions and approximations. Reviewers should judge whether there is sufficient scientific evidence in the open scientific literature to justify the approaches and assumptions being used. Data used for constants and default values in the code should also be assessed for accuracy and applicability in the context of the model.

7.3 Analytical tests

If the programme is to be applied to a situation for which there is a known mathematical solution, analytical testing is a powerful way of testing the correct functioning of a model. However, there are relatively few situations (especially for complex scenarios) for which analytical solutions are known.